Low-Cost and Portable Sound Reduction Box: Innovation for Acoustic Material Performance Measurement

Budi Purwanto*, Melania H. Aryantie, Zulfachmi & Rina Aprishanty

Center for Research and Development of Quality and Environmental Laboratory Research, Development, and Innovation Agency, Ministry of Environment and Forestry of the Republic of Indonesia, Kawasan Puspiptek Gedung 210, South Tangerang 15310, Indonesia
*E-mail: sipurman@gmail.com

Highlights:

- Measurement of the sound reduction index with a sound intensity analyzer using the proposed sound reduction box is an alternative low-cost and portable sound insulation testing method.
- The proposed sound reduction box is a miniature reverberation chamber for testing wood board samples as soundproofing material.
- The proposed sound reduction box is made from medium density fiberboard.
- The combination of the proposed sound reduction box with a sound intensity analyzer was able to produce similar reduction index measurement results as a standard sound insulation testing system.

Abstract. A sound reduction index (RIc) is a laboratory measurement of the sound insulating properties of a material or building element, commonly conducted using a reverberation chamber and an anechoic chamber (SIC), which requires high expenses. This study aimed to perform RIc analysis using a sound reduction box (SRB) to assess the accuracy and precision of the associated result compared to an SIC. The SRB is a miniature reverberation chamber innovation that is owned by the Center for Research and Development of Quality and Environmental Laboratory (P3KLL). The anechoic chamber is substituted by open space as free-field environment. The methods used in this study are based on ISO 15186-1 and ISO 717-1. Measurement was executed using a sound intensity analyzer and data interpretation was done by employing statistical analysis. The types of insulating materials tested were wood boards made of *Shorea* sp., *Swietenia* sp. and *Dryobalanops* sp. with a thickness of 2 cm and 4 cm. Test material measurement was done using the same measuring instruments, sound generators, sound amplifiers, and personnel. The results show that the RIc values were almost the same for both methods (SIC and SRB). When the weighted sound reduction index (Rw) rating calculated from the RIc was compared between the SIC and the SRB, the results were not statistically different. It is interesting that an SRB can be developed in the future as an alternative device for acoustic materials testing.

Keywords: *portable sound reduction box; sound insulation test; sound reduction index; anechoic chamber; sound intensity.*

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1 Introduction

Three different types environments in which noise sources are found in modern laboratories are: anechoic chambers (free field), hemi-anechoic chambers (free field over a reflecting plane) and reverberation chambers (diffused field). In an anechoic chamber, all of the boundaries are highly absorbent and the free-field region extends very nearly to the boundaries of the chamber, while in a reverberation chamber all boundaries are acoustically hard and reflective. In an anechoic chamber, the chamber surfaces are treated with acoustic material such that surface absorption is practically 100% [1]. The reverberant field extends throughout the volume of the chamber, except for a small region in the vicinity of the source [2].

The accurate assessment of the sound insulation properties of panels and partitions is an important area in acoustics [3]. The sound reduction index (RIc) of partitions is used to qualify a considerable range of structures, from fuselage panels to building elements [4]. It is a parameter for measuring acoustic materials that is useful for determining the most appropriate material to use as noise insulation. This measurement is generally done using a reverberation chamber and an anechoic chamber, which requires high expenses. However, measurement on samples of unattended materials is cheaper than installed materials in terms of their application. The various methods for sound reduction index measurement are based on sound pressure (ISO 10140:2010) [5] or sound intensity (ISO 15186-1:2003 and ISO 15186-3:2010) [6-8]. The major variations in the results between the two methods are due to the fact that the pressure-to-pressure method measures the sound reduction index of all the boundary walls inside the SIC, including the wall, the sample under test, baffles and mountings. In contrast, the intensity method only measures the transmission loss of the sample scanned by the intensity probe, so it costs less time to do the measurement and it can also be used on structures in situ [9]. Despite the different methods used, the results from both methods should be comparative to one another [10].

Testing of specimens of noise reducing materials requires sound insulation chamber (SIC) facilities consisting of a reverberation chamber (RC) and an anechoic chamber (AC), as shown in Figure 1. Anechoic chambers (ACs) and reverberation chambers (RCs) are two very different types of laboratory facilities and are widely used in acoustics measurements as well as in electromagnetics [11].

The functions of the two chambers are complementary in acoustic measurements. On a large physical scale both of them require extensive space and the related development costs are not low. The advantage is that testing materials with large dimensions or at industrial scale, such as mining machines, can be carried out at these facilities [12]. However, for research/laboratory purposes, a small sample size is sufficient, where the facilities are accessible and the cost is relatively low. Also, it is often not possible to produce large quantities of the materials [13]. In addition, not many noise research institutions have RC and AC testing facilities.

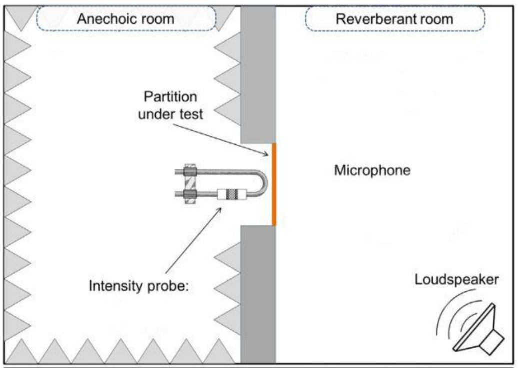

Figure 1 RIc test in SIC.

Through this research, a miniature RC for testing wood board specimens is proposed. The miniature RC in the shape of a sound reduction box (SRB) has dimensions of 1 meter in width, 1 meter in length and 1 meter in height, and its constituent material is medium density fiberboard (MDF), as shown in Figure 2. With an SRB, the cost of RC construction can be reduced and the space needed is less extensive. Test results of an SRB or a small-scale reverberation chamber can be considered intermediate results before being verified with a real RC [1,14]. The function of the AC is substituted with open space to represent a free-field environment, with the background noise level difference higher than 10 dB and no large reflective objects.

Research on making small-scale reverberation chambers is still limited because of issues with low frequency cut-off. Based on the Garuda portal Kemenristekdikti and Ebscohost, in the last 10 years such research has only been conducted by Kim, *et al.* and Rajaram, *et al.* [14,15]. The difference between this research and the two previous researches is that this study focused on testing several types of wood boards, which were judged to be feasible as noise mitigating materials. RIc and Rw are used as parameters in the legal regulations for protection against noise in several European countries concerning the sound insulation of partitions between dwellings [16] and are considered in the design of road, rail, marine and airborne vehicles, where acoustic comfort of passengers matters [17]. Consequently, the acoustic properties of a material are of great importance [18]. The test results from SRB were compared with the test results conducted at the full-scale SIC facilities of the Bandung Institute of Technology.

The purpose of this study was to develop a miniature reverberation chamber and perform an analysis of the accuracy and precision of the associated test results through comparison with an SIC as a reference. The benefits of this research are that the proposed method provides a solution for testing small-size/laboratory scale soundproofing materials, specifically made from wood. The SRB can be further developed for other types of specimens, such as metals, composites, and others. Another limitation is that this miniature RC still needs improvement related to the verification and validation of the methods compared to the requirements for reverberation chambers according to acoustic standards [5].

2 Materials and Methods

The research was conducted in Serpong and Bandung, Indonesia in 2017. We used the SRB as an RC substitute (Figure 2) and open space as an AC substitute. Utilizing the research facility in the Center for Research and Development of Quality and Environmental Laboratory (P3KLL) Serpong, the SRB was lifted 1.5 meter from the ground, positioned at more than 5 meter away from a reflective wall and was tested with low background noise. In comparison, we used a full-scale sound insulation chamber that consisted of a full-scale AC and RC in the Center for Advanced Sciences (CAS) Bandung Institute of Technology (Figure 3). The scope of this research was to develop a portable sound reduction box for conducting RIc tests and Rw rating of soundproofing materials using sound intensity.

Figure 2 SRB with wood board testing material.

(a) (b)

Figure 3 Sound insulation chamber (SIC) located in the Center for Advanced Science (CAS), Bandung Institute of Technology (ITB): (a) reverberation chamber, (b) anechoic chamber.

The methods used in this study are based on ISO 15186-1 and ISO 717-1, using a sound intensity analyzer, statistical data processing, statistical analysis, and data interpretation. A literature study was conducted to find out the novelty of the research and the research preparedness.

Determination of the wood species was based on availability, modulus of elasticity, durability, and especially specific gravity to meet the criteria as a sound proofing material of 20 kg/m^2 [19]. Test material measurement was done using the same measuring instruments, sound generators, and sound amplifiers. The RIc measurements was done using the same measuring instruments, sound generators, sound amplifiers, and personnel. The specimens that were tested using the SRB were made from wood board with square-rectangle sides of the rectangle of 1 meter, with two different thicknesses, i.e. 2 cm and 4 cm.

As a rule of thumb, the minimum density of an effective soundproofing material is 20 kg/m^2 [19]. In addition, for selecting the test material to be used, also the cost and availability of the materials were considered. After considering all the requirements, wood from *Shorea* sp., *Swietenia* sp., and *Dryobalanops* sp. were selected as materials to be tested, as shown in Figure 4.

The samples tested in the SIC were rectangular, with size 140 cm x 140 cm and 2 cm and 4 cm thickness for each rectangle, while those measured in the SRB were rectangular, with size 100 cm x 100 cm and the same thicknesses (2 and 4 cm). The test used Brüel & Kjær 2734 as a signal generator and also as an amplifier.

(a) (b)

Figure 4 Picture of several test materials used in the research: (a) front view, (b) side view.

Furthermore, a Brüel & Kjær 2270 sound intensity analyzer, a Brüel & Kjær 2250 sound pressure level analyzer and a Brüel & Kjær 4231 sound calibrator [20] were also used. In general, RIc measurements consist of three working steps: sound pressure level measurement, sound intensity measurement and calculation of the RIc using formula below [5].

$$\mathrm{RI_C} = \mathrm{L_p} - 6 - \left\{\mathrm{L_I} + 10\log\left(\frac{S_m}{S}\right)\right\} + 10\ log\left(1 + \frac{S_{b2}\lambda}{8V_2}\right) \quad (1)$$

where:

L_p	: the average sound pressure level in the source chamber
L_I	: the measured intensity level normal to the measurement surface
S_m	: the area of the measurement surface
S	: the area of the test specimen
S_{b2}	: the area of all the boundary walls in the receiving chamber
V_2	: the volume of the receiving chamber
λ	: the wavelength of the mid-band frequency

The sound pressure level in the reverberation chamber (RC) was measured as a source chamber, and at least 3 measurement points were measured in the RC located in the SIC and the SRB. Furthermore, sound intensity level measurements were done in the AC located in the SIC and on top of the SRB as receiving chamber.

Each material tested was divided into 4 imaginary segments with scanning methods [6], as shown in Figure 5, after which scanning was applied at 20 seconds of duration to all 4 segments. The RIc values were calculated in a one-third octave band frequency, from 100 Hz to 3150 Hz.

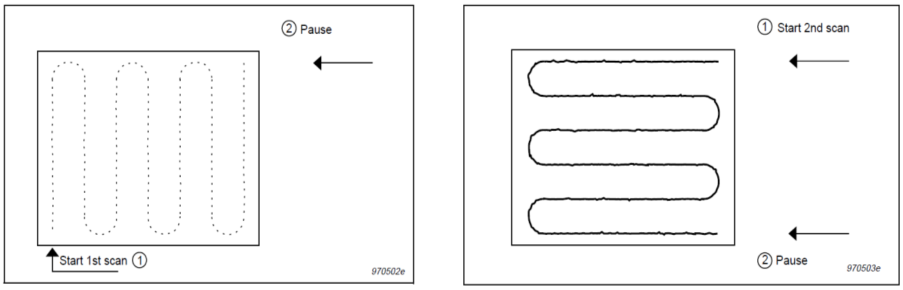

Figure 5 Scanning direction in sound intensity level measurement [21].

The RIc value were then compared with reference values from ISO 717-1:2013 [22] as listed in Table 1 at the measurement frequencies within the range 100 Hz to 3150 Hz to get the Rw rating values (concluded from 500 Hz) for each of the tested materials [23]. This frequency range was also chosen to measure the potential impact on people, considering speech, music and cars as noise sources [24].

Table 1 Reference values for rw rating of airborne sound.

Frequency (Hz)	Reference values (dB)
100	33
125	36
160	39
200	42
250	45
315	48
400	51
500	52
630	53
800	54
1000	55
1250	56
1600	56
2000	56
2500	56
3150	56

The data measurements obtained from the two facilities (SIC and SRB) were then processed with Measurement Partner Suite BZ 5503 [20] and the data were made available in Microsoft Excel format. Finally, all collected data were analyzed using analysis of variance and data comparison and a means separation test was done using the paired t-test.

3 Results and Discussion

All RIc data obtained from this research, concerning two chamber facilities, three different wood materials, two different thicknesses, recorded at 16 different frequencies, are presented in Table 2, indicating a compromising value at 250 Hz. Theoretically, the SRB cut-off frequency is under 630 Hz [25], but looking at the trend indicated by Figures 6, 7 and 8 we can still be confident about 500 Hz.

Table 2 RIc of the test materials in one-third octave band.

Test materials	Frequency (x10 Hz)															
	1	12.5	16	20	25	31.5	40	50	63	80	100	125	160	200	250	315
	dB															
Swietenia sp 4cm*	28	27	27	27	30	30	32	34	34	34	36	37	38	39	40	43
Swietenia sp. 4cm	23	26	25	29	15	30	36	32	29	30	31	32	38	36	40	41
Shorea sp .4cm*	25	27	28	28	31	33	33	34	34	34	36	36	38	40	41	43
Shorea sp. 4cm	28	27	27	30	17	32	39	34	31	32	31	35	39	37	39	42
Dryobalanops sp 4cm*	26	27	27	26	28	32	34	35	32	32	33	35	35	36	38	40
Dryobalanops sp. 4cm	26	27	26	30	16	32	37	33	29	33	28	33	38	37	39	41
Swietenia sp 2cm*	19	21	24	22	26	26	28	28	29	30	30	30	31	33	33	34
Swietenia sp 2cm	30	23	22	25	13	26	32	29	26	28	31	30	35	32	36	34
Shorea sp 2cm*	22	23	24	24	27	27	28	30	30	31	31	32	33	35	37	38
Shorea sp 2cm	21	25	24	27	13	29	34	32	28	32	34	33	39	36	38	39
Dryobalanops sp. 2cm*	20	24	25	24	26	27	28	29	29	31	31	31	32	34	35	36
Dryobalanops sp. 2cm	32	24	23	27	14	28	34	31	27	31	30	30	35	31	33	34

Note. *mark after test material names means the test are conducted at SIC facility.

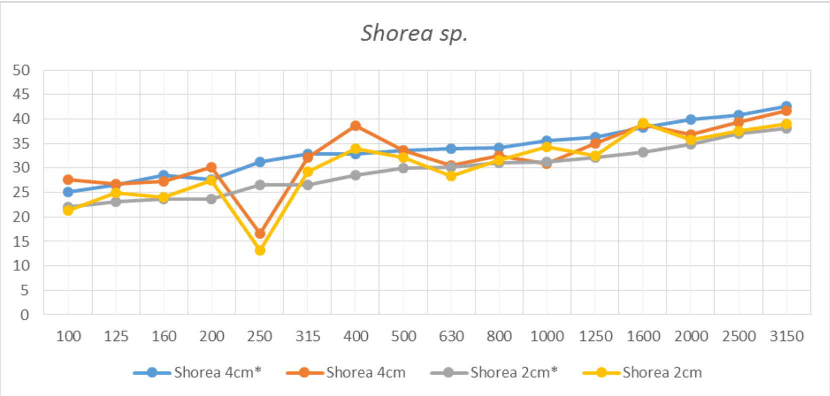

Figure 6 RIc values of *Shorea* sp. tested with SRB and SIC.

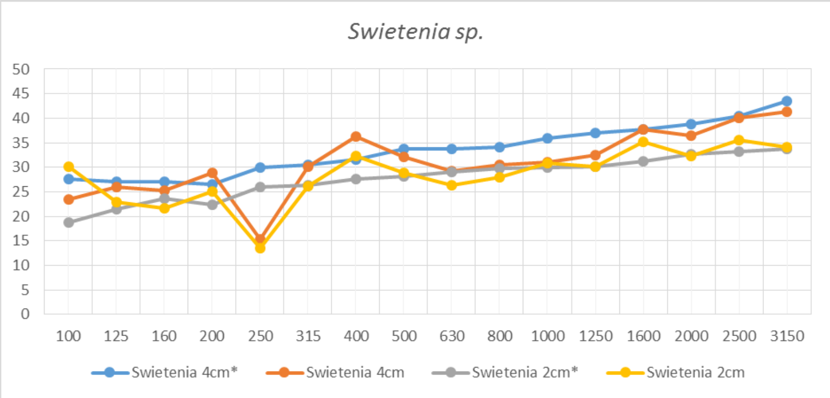

Figure 7 RIc values of *Swietenia* sp. tested with SRB and SIC.

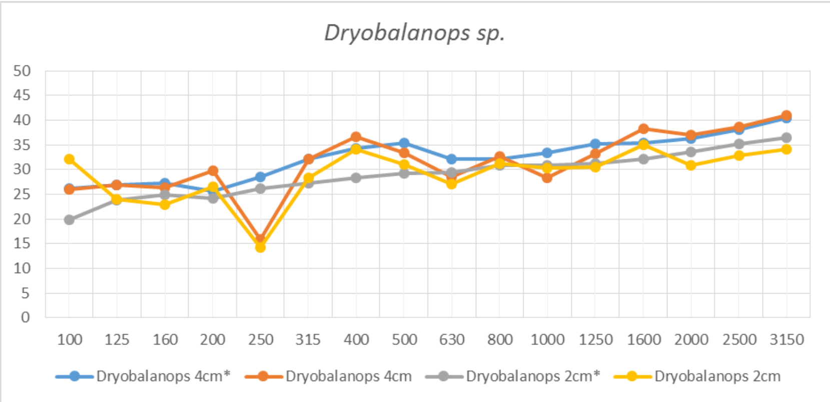

Figure 8 RIc values of *Dryobalanops* sp. tested with SRB and SIC.

All RIc readings were then converted using reference values provided by ISO 717-1:2013 [18]. The results of the converted values are expressed as weighted sound reduction index (Rw) and are summarized in Table 3. In most cases the RIc values increased with an increase of the reading frequency. Note also that the sound reduction, indicated by the RIc values, also increased with an increase of wood thickness. It has been reported that RIc measurement using a sound intensity analyzer conducted in a laboratory is considered to be more precise than field measurements [26].

Statistical inference in terms of effect of treatment, in this case focused only on two different chambers, is presented in Table 4. The other parameters observed will be discussed in a separate report. Based on Table 3, it is apparent that the level of the weighted sound reduction index in the SIC was somewhat higher than that of the SRB. However, based on a mean separation test employing the paired t-test, shown in the analysis of variance table (Table 4), it can be concluded that there was no statistically significant difference between the two chambers.

The average value of the different values of Rw between the two measurement procedures was only 1.7 dB. This research also indicates that all the wood materials used as covering, *Shorea* sp., *Swietenia* sp., and *Dryobalanops* sp., were comparably the same in terms of their physical quality. The average magnitude of Rw for *Shorea* sp. was 34 dB, while the average magnitude of Rw for *Swietenia* sp. was 33 dB, and the average magnitude of Rw for *Dryobalanops* sp. was also 33 dB.

It is interesting to note that there was no significant statistical difference between the SIC in terms of the weighted sound reduction index (Rw) and the SRB. This strongly suggests that an SRB can be a substitute for an SIC facility. Bearing in mind that the cost of an SRB is much lower than that of an SIC facility, it is important to verify this result in the future.

Table 3 Rw of the test materials.

Test materials	**SIC (dB)**	**SRB (dB)**	**Difference (dB)**
Swietenia sp. 4cm	37	33	4
Shorea sp. 4cm	37	34	3
Dryobalanops sp. 4cm	36	34	2
Swietenia sp. 2cm	31	31	0
Shorea sp. 2cm	33	33	0
Dryobalanops sp. 2cm	32	31	1

Table 4 Analysis of variance of T-test between SIC and SRB.

Test materials	**SIC**	**SRB**
Mean	34.33333333	32.66666667
Variance	7.066666667	1.866666667
Observations	6	6
Pooled variance	4.466666667	
Hypothesized mean difference	0	
df	10	
t Stat	1.365895912	
P(T <= t) one-tail	0.100951102	
t Critical one-tail	1.812461123	
P(T <= t) two-tail	0.201902204	
t Critical two-tail	2.228138852	

4 Conclusion

This research showed that the Rw tests carried out with the SIC in Bandung Institute of Technology and and an SRB owned by the Center for Research and Development of Quality and Environmental Laboratory were not significantly different. The types of wood boards tested were *Shorea* sp., *Swietenia* sp. and *Dryobalanops* sp. at 2 cm and 4 cm wood thickness, so for now SRB is proposed as a miniature RC for testing wood board samples as soundproofing materials. However, the results of this research still require further validation and verification before being designated a prototype. The advantage of using an SRB are the much lower cost to build one and the small size of the test specimens required. Still, it is important to note that it require investment in a sound intensity analyzer, which is costly and does not cover low frequencies.

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Nomenclature

AC	=	anechoic chamber
CAS	=	Center for Advanced Sciences
ISO	=	International Organization for Standardization
ITB	=	*Institut Teknologi Bandung* (Bandung Institute of Technology)
MDF	=	medium density fiberboard
P3KLL	=	*Pusat Penelitian dan Pengembangan Kualitas dan Laboratorium Lingkungan* (Center for Research and Development of Quality and Environmental Laboratory)
RC	=	reverberation chamber
RIc	=	sound reduction index
Rw	=	weighted sound reduction index
SIC	=	sound insulation chamber
SRB	=	sound reduction box

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